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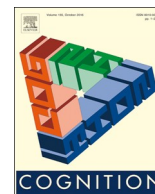
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Original Articles

Investigating the relationship between fast mapping, retention, and generalisation of words in children with autism spectrum disorder and typical development

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ABSTRACT

While many studies have investigated how autism spectrum disorder (ASD) impacts how children identify the meanings of new words, this task alone does not constitute learning. Here we investigate fast (referent selection) and slow (retention, generalisation) word learning processes as an integrated system and explore relationships between these mechanisms in ASD and typical development. In Study 1, children with ASD and typically developing (TD) children matched on receptive vocabulary utilised mutual exclusivity to identify referents of unfamiliar words, but showed substantially reduced accuracy on delayed retention and generalisation trials. Thus, Study 2 investigated whether re-directing children's attention to target objects following referent selection would enhance delayed retention. Participants received either social feedback (target objects were labelled and highlighted via social cues) or non-social feedback (target objects were labelled and highlighted via a flashing light). In both conditions, children with ASD were less accurate in their use of mutual exclusivity to fast-map novel words than TD children. However, children with ASD who received social feedback responded more accurately on delayed retention and generalisation trials than TD controls, and children with ASD who received non-social feedback or no feedback (in Study 1). Our findings imply that fundamental word learning mechanisms, and the relationships between them, are not qualitatively different in ASD. We argue that ASD may affect the efficiency of these mechanisms by disrupting children's intake of linguistic input in natural environments, but difficulties may be mitigated by presenting visual and auditory stimuli in a way that appeals to the population's strengths.

1. Introduction

Language acquisition is at the heart of children's cognitive and social development (Carpenter, Nagell, & Tomasello, 1998; Tomasello, 2003; Vygotsky, 1962). The ability to learn words is central to children's engagement with the social world, however, this skill is substantially impacted by autism spectrum disorder (ASD; Tager-Flusberg & Kasari, 2013). Whereas typically developing (TD) children usually utter their first words by 12 months, children with ASD start to speak at 38 months on average (Ellis Weismer & Kover, 2015; Howlin, 2003; Thurm, Manwaring, Swineford, & Farmer, 2015). Although the majority of individuals with ASD eventually acquire functional language, approximately 25–30% have minimal-to-no spoken language throughout childhood (Anderson et al., 2007; Norrelgen et al., 2015). In order to generate effective interventions that promote word learning in

children with ASD, it is vital to understand which processes are atypical in their functioning. Previous research has predominantly targeted differences in how children with ASD identify the meanings of unfamiliar words, yet this process is just one component of word learning (McMurray, Horst, & Samuelson, 2012). Comparatively little attention has been paid to potential differences in retention and generalisation of word-referent relationships, and how these processes fit together as an integrated system in word learning.

To learn a word, children must establish a lasting relationship between the word's phonological form and its meaning. Once a spoken word has been identified, the process of mapping to meaning requires: (a) identification of a word's intended meaning (referent selection), (b) storage of the word-referent pairing in memory enabling later retrieval (retention), and (c) appropriate extension of the word to new category members (generalisation) (Gleitman, 1990).

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In the context of a speaker naming an object, action, or feature of the environment, referent selection requires solving the problem of referential ambiguity (there are often multiple potential targets for a newly heard word; Markman, 1989) and involves narrowing attention down to a single target. This attentional narrowing can be directed by numerous sources of information, including social cues and linguistic constraints. For example, TD infants will spontaneously consult a speaker's face when they hear a novel word and identify a referent based on their direction of gaze (e.g. Baldwin, 1991; Preissler & Carey, 2005). By 2 years, TD children also apply the 'mutual exclusivity' (ME) principle (the assumption that a word has only one referent) to assign novel words to unfamiliar objects (Carey, 1978; Markman & Wachtel, 1988; Merriman & Bowman, 1989). Children's use of this heuristic is conventionally tested by presenting a single unfamiliar object alongside one or more familiar objects, and asking them to identify the referent of a novel word (e.g. Dautriche, Swingley, & Christophe, 2015; Halberda, 2003; Horst & Samuelson, 2008). As children already know the name(s) of the familiar object(s), they infer that the novel word must refer to the unfamiliar object on the basis of ME.

However, accurate referent selection does not constitute word learning. Horst and colleagues have repeatedly demonstrated that TD children often forget new words just 5 min after performing at ceiling on an ME referent selection task (Axelsson, Churchley, & Horst, 2012; Horst & Samuelson, 2008; Horst, Scott, & Pollard, 2010). This suggests that referent selection and retention are subserved by different mechanisms. Indeed, accurate referent selection can be achieved by merely attending to known competitors and excluding them through a process of elimination, whereas retention requires children to encode the novel object, the novel word, and the relationship between the two (Axelsson et al., 2012).

The 'dynamic associative account' (Kucker, McMurray, & Samuelson, 2015; McMurray et al., 2012; Samuelson & McMurray, 2017) posits that referent selection and retention draw on separate 'fast mapping' and 'slow learning' processes. According to this theory, retention is underpinned by associative learning mechanisms consistent with sources of information such as cross-situational statistical co-occurrences between particular words and features of the environment (McMurray et al., 2012). Importantly, retention of novel words can be accelerated by feedback that directs TD children's attention towards intended referents and away from competitors (strengthening associative relationships). In Axelsson et al.'s (2012) ME referent selection task with TD 24-month olds, the experimenter repeated the names of unfamiliar target objects after children's responses. During naming, children's attention was directed to the intended referent and/or away from competitors by the experimenter pointing to the novel object, illuminating the novel object, concealing the known objects, or both illuminating the novel object and concealing the known objects (all while looking directly at the child and not at the objects). The results showed that children's initial referent selection accuracy was equivalent across conditions. However, retention following a 5-min delay was most accurate when target objects were illuminated, rather than pointed to. These findings suggest that word learning can be facilitated by focusing children's attention on an intended referent once they have actively excluded competitors. Furthermore, the observed between-condition differences indicate that retention of novel name-object associations can be effectively influenced by non-social attention-directing feedback.

It has been widely argued that children with ASD have difficulty learning words due to their reduced sensitivity to social cues that support referent selection (e.g. Baron-Cohen, Baldwin, & Crowson, 1997; Preissler & Carey, 2005; Gliga et al., 2012). For example, a seminal study by Baron-Cohen et al. (1997) discovered that children with ASD and profound language impairments mapped novel labels onto objects that were the focus of their own attention, rather than a speaker's intended referents. By contrast, TD children matched on verbal mental age (of around 2 years) utilised the speaker's direction of

gaze as a cue to mapping. More recently, Gliga et al. (2012) found that linguistically impaired children with ASD could follow gaze to the correct referents of words, but then failed to map word-referent relationships. These studies suggest that word learning in language-impaired children with ASD may not be informed by cues to a speaker's referential intent (although this may not be true for individuals with stronger verbal skills; Bean Ellawadi & McGregor, 2016; McGregor, Rost, Arenas, Farris-Trimble, & Stiles, 2013; Norbury, Griffiths, & Nation, 2010).

By contrast, numerous studies have demonstrated that children across the ASD spectrum can accurately identify the referents of unfamiliar words via ME (de Marchena, Eigsti, Worek, Ono, & Snedeker, 2011; Parish-Morris, Hennon, Hirsh-Pasek, Golinkoff, & Tager-Flusberg, 2007; Preissler & Carey, 2005). If children with impaired language can employ heuristics that facilitate accurate mapping of novel word-object relationships, it may be possible to scaffold vocabulary acquisition by presenting language in a manner that affords the use of these strategies. Supporting referent selection can have positive effects on retention of vocabulary, as Bion, Borovsky, and Fernald (2013) showed a correlation between these processes in TD children aged 18–30 months. We will explore this hypothesis by examining predictive inter-relationships between fast and slow word learning mechanisms, and identifying how these relate to children's receptive vocabulary.

In comparison to referent selection, little is known about how ASD affects lexical retention. Norbury et al. (2010) found that high-functioning children with ASD could retain word-object mappings as accurately as TD controls, but they remembered significantly less semantic information about referents over time. In Bedford et al. (2013), 2-year-old infants at high-risk of developing ASD and low-risk controls completed an ME referent selection task with ostensive social feedback, followed by a retention test after 5 min. Receiving social feedback significantly improved retention of newly-learned words in low-risk infants, but not high-risk infants. The authors propose that failure to learn from social feedback may inhibit retention of novel words in children who develop ASD.

To use language flexibly, children must also learn how to appropriately generalise words to previously unseen members of the same semantic category. By approximately 24-months, TD children reliably infer that noun-referent relationships are constrained by shape, and thus generalise newly-learned words to novel objects based on this feature, rather than other perceptual properties (e.g. colour, size, texture; Landau, Smith, & Jones, 1988; Samuelson & Smith, 1999; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002). The emergence of this "shape bias" coincides with children's acquisition of approximately 50–150 count nouns (Gershkoff-Stowe & Smith, 2004; Samuelson & Smith, 1999), and Smith et al. (2002) propose that the process of learning object names selectively tunes children's attention to shape, which in turn accelerates their acquisition of new object names (also see Perry, Axelsson, & Horst, 2016).

However, generalisation of verbal labels to novel referents may be impaired in some children with ASD. Tek, Jaffery, Fein, and Naigles (2008) and Potrzeba, Fein, and Naigles (2015) found that preschoolers with ASD did not reliably extend novel labels on the basis of shape, despite possessing expressive vocabularies in excess of 100 count nouns. Hartley and Allen (2014) reported that language-impaired children with ASD frequently extended labels to novel referents on the basis of shape (a category-defining cue) or colour (a category-irrelevant cue). Conversely, TD children matched on receptive vocabulary only extended labels to items that matched the target's shape. These findings indicate that early lexical development in ASD could be hindered by the absence of a shape bias. It may be that children with ASD fail to identify shape as the perceptual constraint that organises word-referent categories due to their tendency to process visual information at a local, rather than global, level (Happé & Frith, 2006; Mottron, Dawson, Soulières, Hubert, & Burack, 2006). Crucially, no research to date has examined how generalisation difficulties inter-relate with referent

selection and retention in ASD. Investigating word learning as an integrated system is necessary to spotlight the location and nature of specific strengths and weaknesses that mediate vocabulary development in ASD.

The present study, for the first time, systematically explored the relationship between fast mapping, retention, and generalisation in children with ASD and typical development. In Study 1, children with ASD and TD controls identified the meanings of 4 novel words in a standard ME referent selection task. Their retention and generalisation of word meanings was then assessed after a 5-min delay. Based on previous evidence (e.g. Preissler & Carey, 2005), we predicted that both populations would respond accurately on the referent selection trials, but this might not be sufficient to support above-chance retention or generalisation. However, if word meanings were retained, we expected to observe differences in generalisation; TD children would prioritise shape as a basis for extending labels to novel referents, but children with ASD might not. In Study 2, we tested the extent to which ostensive feedback, following children's referent selection, affected word learning for children with ASD and TD controls. To examine how individual differences influence these processes, we recruited children with ASD with varying degrees of language delay (relative to their chronological age). In comparison to most prior work with TD children, our samples were older and more advanced in terms of receptive language development. Thus, we can be confident that any between-population differences in word learning are not the consequence of insufficient general language skills in the ASD samples.

2. Study 1: Fast mapping, retention, and generalisation of novel words in children with ASD and typical development

2.1. Method

2.1.1. Participants

Participants were 16 children with ASD (13 males, 3 females; M age = 8.79 years; SD = 2.79 years) recruited from specialist schools, and 16 TD children (6 males, 10 females; M age = 5.57 years; SD = 1.11 years) recruited from mainstream schools and nurseries (see Table 1). Groups were matched on receptive vocabulary as measured by the British Picture Vocabulary Scale (BPVS; ASD: M age equivalent = 5.32 years, SD = 1.97; TD: M age equivalent = 5.81 years, SD = 1.2; Dunn, Dunn, Whetton, & Burley, 1997), $t(30) = 0.86$, $p = .40$. Receptive vocabulary was selected as the primary matching criterion because it reflects children's ability to learn word-referent relationships – the linguistic ability at the heart of this research (Bion et al., 2013; Kalashnikova, Mattock, & Monaghan, 2016). All children had normal or corrected-to-normal colour vision. Children with ASD were previously diagnosed by a qualified educational or clinical psychologist, using standardised instruments (i.e. Autism Diagnostic Observation Scale and Autism Diagnostic Interview – Revised; Lord,

Rutter, & Le Couteur, 1994, 2002) and expert judgement. Diagnoses were confirmed via the Childhood Autism Rating Scale 2 (Schopler, Van Bourgondien, Wellman, & Love, 2010), which was completed by each participant's class teacher (ASD M score = 36.59, SD = 6.07; TD M score = 15.38, SD = 0.5). Children with ASD were significantly older ($t(30) = 4.29$, $p < .001$, $d = 1.65$), and had significantly higher CARS scores ($t(30) = 13.94$, $p < .001$, $d = 6.46$) than the TD children. Children's non-verbal intellectual abilities were measured using the Leiter-3 (Roid, Miller, Pomplun, & Koch, 2013). The mean (age-normed) IQ for the ASD group was 85.69 (SD = 17.82), and the mean IQ of the TD group was significantly higher at 100.88 (SD = 4.56), $t(30) = 3.30$, $p = .002$, $d = 1.36$. However, the groups' raw scores on the Leiter-3 did not significantly differ (ASD M score = 73.19, SD = 16.33; TD M score = 69.50, SD = 13.42), $t(30) = 0.70$, $p = .49$, indicating that their non-verbal cognitive abilities were similar at time of testing (when age was not considered). All procedures performed in this study (Study 1 and Study 2) involving human participants were in accordance with the ethical standards of the institutional and national research committee. Informed consent was obtained from parents/caregivers prior to children's participation.

2.1.2. Materials

Stimuli included four novel words (dax, wug, yok, lep) selected from the NOUN database (Horst & Hout, 2016), 11 familiar objects, and 12 unfamiliar objects (see Fig. 1). Familiar objects were selected on the basis that most children understand their linguistic labels by 16-months (Fensen et al., 1994). Unfamiliar objects were selected on the basis that children would not know their linguistic labels. Three familiar objects (models of a dog, a flower, and a car) were employed in the warm up trials. The unfamiliar objects were divided into four sets. Each set included a 'named object' (which was paired with a novel word during referent selection trials) and a 'shape match' (a differently-coloured variant of the named object). Each shape match was the same colour as a named object from a different set, and therefore served as a 'colour match'. The remaining eight familiar objects (miniature shoe, spoon, book, plastic tree, toy cow, plastic banana, children's cup, toy horse) were divided into pairs and presented alongside unfamiliar objects in the referent selection trials.

Objects were presented at each stage of the word learning task via a specially-designed tray with five sections, although only the sections positioned to the far left, centre, and far right were used in both Study 1 and Study 2. These three sections were separated by 17 cm gaps.

2.1.3. Procedure

Participants were tested individually in their own schools and were accompanied by a familiar adult when required. Children were verbally praised for attention and good behaviour. Corrective reinforcement was only provided in the warm up trials. Children were administered the BPVS and Leiter-3 and then completed the word learning task 1-week

Table 1
Characteristics of samples in Study 1 and Study 2 (standard deviation and range in parentheses).

Population	Condition (Study)	<i>N</i>	Chron. age (years)	BPVS age equiv. (years)	CARS score	Leiter-3 raw score
TD	No feedback (Study 1)	16	5.57 (1.11; 3.92–8.17)	5.81 (1.20; 4.17–8)	15.38 (0.50; 15–16.5)	69.50 (13.42; 48–90)
	Social feedback (Study 2)	16	5.41 (1.22; 3.42–7.17)	5.75 (1.42; 3.42–8)	15.44 (0.73; 15–17)	66.00 (13.39; 48–95)
	Non-social feedback (Study 2)	16	5.08 (1.04; 3.25–7)	5.77 (1.42; 3.42–7.83)	15.03 (0.13; 15–15.5)	63.94 (11.97; 47–88)
ASD	No feedback (Study 1)	16	8.79 (2.79; 5–15.58)	5.32 (1.97; 2.83–9.58)	36.59 (6.07; 28.5–48)	73.19 (16.33; 44–101)
	Social feedback (Study 2)	17	8.46 (2.01; 4.83–11.83)	5.08 (2.06; 2.17–8.08)	36.47 (5.70; 27–47.5)	65.76 (18.67; 41–113)
	Non-social feedback (Study 2)	17	8.79 (2.76; 4.33–15.42)	5.11 (1.89; 2.92–8.17)	36.21 (7.04; 27.5–58)	72.00 (23.96; 47–123)

Note. TD: typically developing; ASD: autism spectrum disorder; BPVS: British Picture Vocabulary Scale; CARS: childhood autism rating scale.

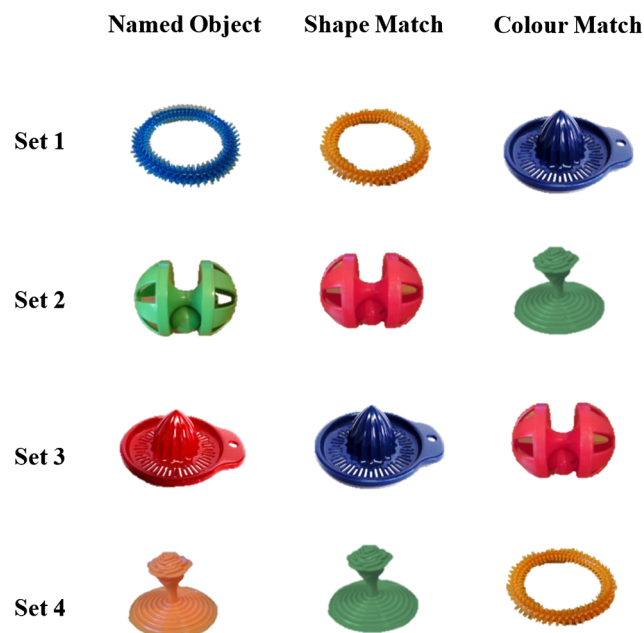


Fig. 1. Sets of unfamiliar objects used in Studies 1 and 2.

later. The word learning task consisted of the following stages delivered in a fixed order: 1. Warm-up trials, 2. Referent selection trials, 3. Test object familiarisation, 4. Delay, 5. Retention and generalisation trials.

2.1.3.1. Warm-up trials. The task began with 3 warm-up trials. On each trial, children were presented with three familiar objects on different sections of the tray. The experimenter waited silently for approximately 3 s before asking the child to identify one of the objects (e.g. “Which is the car? Can you see the car? Show me the car.”) and sliding the tray forward. If the child was reluctant to respond, the experimenter provided up to 4 additional prompts per trial. Following a correct response, the experimenter issued praise and reinforced the identity of the object (e.g. “Great job, that is the car!”). Following an incorrect response, the experimenter provided corrective feedback (e.g. “Actually, this is the car. Can you touch the car? Well done, you touched the car!”). The experimenter then retrieved the tray and re-ordered the objects for the next trial. Children were asked to identify a different object (dog, flower, car) in a different location on the tray (left, centre, middle) across trials.

2.1.3.2. Referent selection trials. Eight referent selection trials immediately followed the warm-up trials and had an identical format, except children did not receive feedback related to their responses (the experimenter just said “thank you”). Children were presented with 4 sets of objects, each consisting of one unfamiliar object, and two familiar objects. Each set was presented twice; once the experimenter requested the familiar object (‘familiar name trial’; e.g. “Which is the banana? Can you see the banana? Show me the banana.”) and once for the unfamiliar object (‘novel name trial’; “Which is the dax? Can you see the dax? Show me the dax.”). As young children display an intrinsic preference for novelty in referent selection tasks (e.g. Horst, Parsons, & Bryan, 2011), familiar name trials were included to prevent participants from learning to simply choose the novel object and encourage them to examine every item. Indeed, effective fast mapping requires children to attend to known competitors in order to exclude them as referents for a novel word (Halberda, 2003). Novel name trials were designed to promote active learning of new word-object pairings. As participants already have names for the two familiar objects, they should apply the mutual exclusivity principle and assign the novel label to the unfamiliar object.

The order of trials was pseudo-randomised with the constraint that the same set of objects was never presented on consecutive trials and no more than two trials of the same type (familiar name or novel name) were experienced sequentially. Positioning of objects on the tray (left, middle, right) was pseudo-randomised across trials with the constraint that the requested object did not appear in the same location more than twice consecutively. The four novel words (dax, wug, yok, lep) were randomly allocated to the four unfamiliar objects for each participant.

2.1.3.3. Test object familiarisation. Test object familiarisation immediately followed the final referent selection trial. Children were familiarised with the as-yet unseen shape/colour match objects before their appearance in the subsequent retention and generalisation trials. The purpose of this stage was to minimise novelty and familiarity preferences, increasing the likelihood that children would select objects based on their memory of word-object mappings. Each of the shape/colour match objects was paired with a previously seen (named) unfamiliar object belonging to a different set. Pairs of objects were presented on the left and right sections of the tray (approximately 48 cm apart) and the experimenter instructed children to “look!”. The experimenter silently counted to six before removing the objects from view and presenting the next pair until all of the novel objects had been seen. Children were allowed to touch the objects if they wished (as they were allowed to touch the objects in the referent selection trials). Object pairings were fixed and children received one of two presentation orders. Positioning of named objects and shape/colour match objects to the left and right was randomised.

2.1.3.4. Delay. Immediately following test object familiarisation, the child played with the experimenter for 5 min. None of the familiar or unfamiliar objects used in the experiment were visible during this stage.

2.1.3.5. Retention and generalisation trials. To re-engage children’s attention to the task, the experimenter selected 3 familiar objects at random and administered one warm-up trial as described above. Eight retention trials and eight generalisation trials immediately followed (see Fig. 2 for an illustration of each trial type). Each novel word was tested on 2 retention trials and 2 generalisation trials. For retention trials, 3 named objects were presented in different sections of the tray (left, centre, right). The experimenter asked children to identify one of the objects (e.g. “Which is the dax? Can you see the dax? Show me the dax.”) and then slid the tray forward. Target objects were named three times to ensure that children with ASD (who often benefit from repeated verbal instructions; Hartley & Allen, 2015; Siegel, Goldstein, & Minshew, 1996) identified which word was being requested. The purpose of these trials was to assess children’s memory of the exact word-referent pairings that were experienced during the referent selection trials. For generalisation trials, children were presented with a differently coloured variant of a target object (shape match), an object that matched the target object on colour but not shape (colour match), plus a shape/colour match object for another set. Children were asked to identify which of these novel objects was a referent for the word paired with the target object (e.g. “Which is the dax? Can you see the dax? Show me the dax”). The purpose of these trials was to assess whether children’s extension of labels to novel referents is systematically influenced by shape or colour. Importantly, all choice objects were of equal familiarity in both retention trials (all were named in referent selection trials) and generalisation trials (all were introduced during test object familiarisation and were differently coloured variants of a named object).

To provide the necessary level of control when presenting stimuli, object groupings were fixed. Trials were administered in one of 8 possible orders (evenly allocated across participants in each sample). For each order, the experimenter alternated between retention and generalisation trials and never requested the same word on consecutive trials. Half of the orders started with retention trials and half started

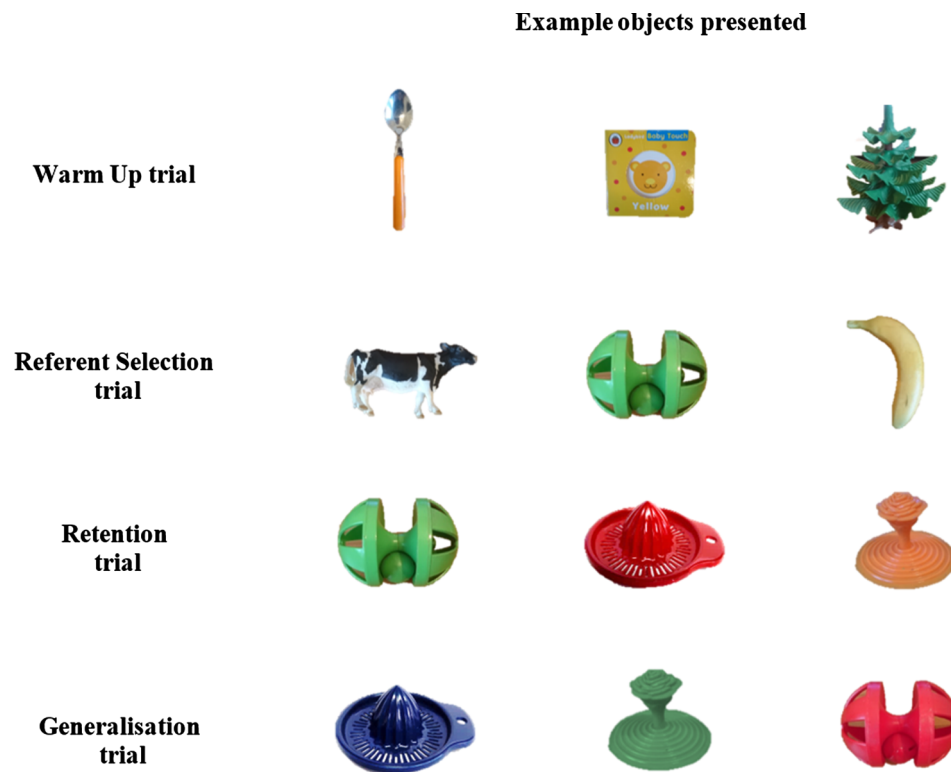


Fig. 2. Example objects presented at each stage of Studies 1 and 2. The target object is the middle object in the referent selection trial, the left object in the retention trial, and the right object in the generalisation trial.

with generalisation trials. The positioning of object sets in the sequence of trials was systematically varied across orders. In the retention trials, the 4 named objects each served as a target on two trials and a foil on four trials. In the generalisation trials, each shape match object (a) corresponded with the requested word on 2 trials (i.e. acting as the target), (b) served as a colour match on 2 trials, and (c) served as a distracter on 2 trials. Positioning of objects on the tray (left, middle, right) was pseudo-randomised across trials with the criterion that the requested object did not appear in the same location more than twice consecutively.

2.2. Results

The data for Study 1 and Study 2 are archived at <http://reshare.ukdataservice.ac.uk/853520/>.

2.2.1. Referent selection

Participants were scored out of four on familiar and novel referent selection trials (see Fig. 3). TD children and children with ASD did not differ on familiar trials (both groups achieved 100% accuracy). An independent samples *t*-test indicated a borderline significant difference between the groups on novel trials in which children had to use ME (TD children responded more accurately than children with ASD), $t(30) = 1.86, p = .07, d = 0.46$.

2.2.2. Retention & generalisation trials

Participants were scored out of eight on retention and generalisation trials (each novel word was tested twice on each trial type; see Fig. 3). Children were considered to have responded correctly if they selected the object that the experimenter labelled with the requested word during the referent selection stage. To compare performance of TD children and children with ASD across trial types, the data were entered into a 2(Population: TD, ASD) \times 2(Trial Type: retention, generalisation) mixed ANCOVA. Novel referent selection accuracy was

included as a covariate to control for initial between-group differences in word-referent mapping on children's retention and generalisation accuracy. The analysis revealed a significant Population \times Trial Type interaction, $F(1, 29) = 5.66, MSE = 1.32, p = .02, \eta_p^2 = 0.16$, which was explored via a series of Bonferroni-adjusted pairwise comparisons (controlling for referent selection accuracy). While the populations did not differ on their retention accuracy ($p = .95$), children with ASD achieved significantly higher accuracy on generalisation trials than TD children ($p = .018, \eta_p^2 = 0.18$). The difference in accuracy between retention and generalisation trials was not statistically significant for TD children ($p = .10$) or children with ASD ($p = .29$). The results were qualitatively similar when an ANOVA was conducted without novel referent selection accuracy as a covariate, except that children with ASD responded significantly more accurately on generalisation trials than retention trials ($p = .04$). Additional analyses confirmed that these results were not significantly influenced by participant gender.²

2.3. Discussion

Both populations spontaneously utilised ME to accurately identify the referents of unfamiliar words, but showed substantially reduced accuracy on the delayed retention and generalisation trials. Comparisons between retention and generalisation trial performance revealed striking and unexpected response patterns. While the two groups achieved similar accuracy on retention trials, children with ASD were significantly more accurate than TD controls on generalisation trials.

² As our samples were not matched on gender, we conducted follow-up analyses to explore the influence of this variable. Each measure of word learning accuracy (i.e. familiar referent selection, novel referent selection, retention, generalisation) was entered into a 2(Population: ASD, TD) \times 2(Gender: Female, Male) ANOVA. No significant main effects of Gender, or interactions involving Gender, were detected in either Study 1 or Study 2.

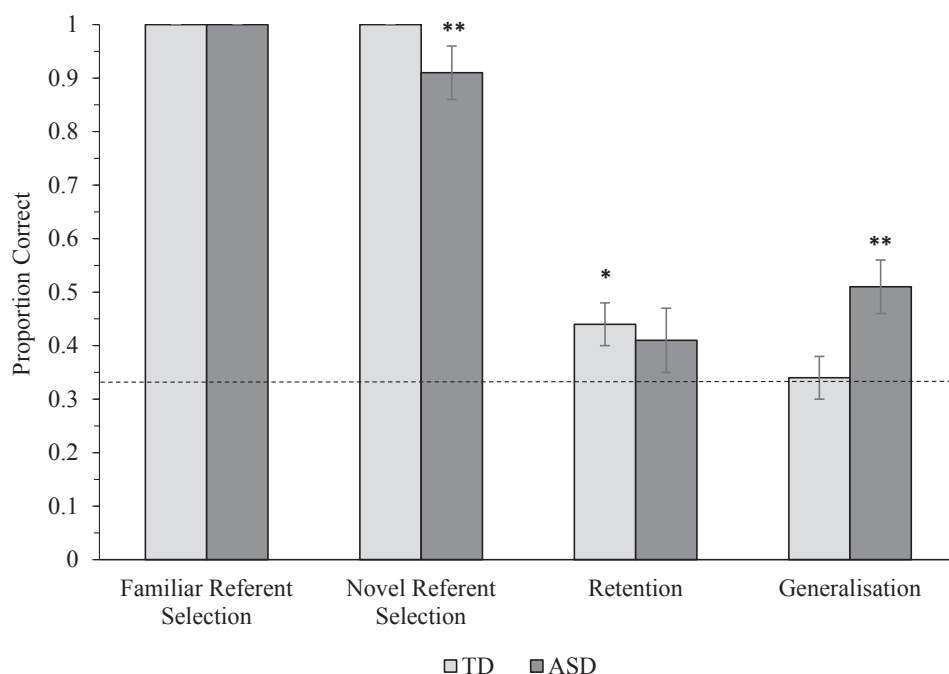


Fig. 3. Average referent selection, retention, and generalisation trial accuracy for typically developing (TD) children and children with autism spectrum disorder (ASD) in Study 1. Error bars show ± 1 SE. Stars above columns indicate where below-ceiling performance was significantly more accurate than expected by chance, indicated by the dotted line (* $p < .05$; ** $p < .01$).

The performance of children with ASD on referent selection trials supports existing evidence that ME-based fast mapping is a key ability for this population (e.g. Preissler & Carey, 2005; de Marchena et al., 2011). These findings confirm that children with ASD are adept at mapping new word-referent relationships when environmental constraints afford the use of known vocabulary to resolve referential ambiguity. However, their near-ceiling fast mapping accuracy was not maintained for the delayed retention and generalisation trials. In line with previous studies with younger TD children (e.g. Horst & Samuelson, 2008), both populations failed to retain word-object pairings that they successfully identified during referent selection. Thus, for TD children older than 2-years and children with ASD, merely identifying the correct referent of a newly-heard word in a single naming event does not reliably establish a robust representation of meaning that immediately integrates into their vocabulary.

Previous research has shown impairments in shape-based generalisation in children with ASD (Hartley & Allen, 2014; Potrzeba et al., 2015; Tek et al., 2008), but our results did not. This finding may be explained by differences in methodology and/or sample composition. In terms of methodology, prior studies that report atypical generalisation in ASD employed tasks that allowed children to select multiple referents for target words (either through explicit gestural responses or through gaze shifting), whereas the present study employed a forced-choice task. It may be that children with ASD prioritise shape when required to select a single referent from an array, but are willing to extend labels based on non-shape properties when their generalisation is unrestricted and several objects can be identified as referents for a target word (e.g. Hartley & Allen, 2014). Alternatively, in terms of population differences, children with ASD may need to acquire a substantially larger vocabulary than TD children before the shape bias emerges. ASD samples in previous studies that did *not* identify a shape bias had average verbal mental ages between 23 and 42 months, whereas the average receptive vocabulary age equivalent of our ASD sample was approximately 64 months. Field, Allen, and Lewis (2016) also recently observed a preference for shape-based label extension in children with ASD whose verbal mental ages exceeded 54 months. Viewed alongside those findings, our data corroborate Field's claim that the development of the shape bias in ASD may be delayed.

However, it is more challenging to explain why our sample of children with ASD generalised labels significantly more accurately than

TD peers matched on receptive vocabulary. It is also surprising that retrieval of meaning would be more accurate when only shape is available as a cue, and less accurate when both shape and colour are available. Given the possibility that these unpredicted effects are due to random variability, we first attempt to replicate these results in Study 2 before speculating on potential causes.

Although identification of meaning may be facilitated by configuring environments that afford the use of ME, there is clearly a high probability that newly-mapped word-referent relationships will be forgotten after a short delay. Thus, in Study 2, we investigated whether children's delayed retention and generalisation can be enhanced.

In Study 2, children with ASD and TD children completed variations of our word learning task that incorporated ostensive feedback following children's referent selection. Half of each population received social feedback (head turn, gaze shift, and point towards the intended referent) and half received non-social feedback (illumination of intended referent) that focused children's attention on target objects. We predicted that these modes of feedback would elicit improved retention in both populations above that found in Study 1. For TD children, we anticipated similar benefits in both conditions as social feedback in this study was more salient than in Axelsson et al. (2012), where social feedback was less effective than illuminating referents. For children with ASD, we predicted that decreased sensitivity to social cues might inhibit their capacity to benefit from social feedback, but their retention might be enhanced by non-social feedback that is attentionally salient. Observation of these between-condition effects would (a) suggest that ASD impacts language acquisition by inhibiting children's ability to benefit from social feedback during naturalistic interactions (Bedford et al., 2013), and (b) highlight a potential route to enhancing long-term word learning in ASD despite deficits in social interaction and communication.

3. Study 2: The effect of feedback on word learning in children with ASD and typical development

3.1. Method

3.1.1. Participants

Participants were 34 children with ASD (28 males, 6 females; M age = 8.63 years; SD = 2.38) recruited from specialist schools, and 32

TD children (22 males, 10 females; M age = 5.25 years; SD = 1.13) recruited from mainstream schools and nurseries. All children had normal or corrected-to-normal colour vision. None of these children participated in Study 1. Children with ASD were previously diagnosed by a qualified educational or clinical psychologist, using standardised instruments (i.e. Autism Diagnostic Observation Scale and Autism Diagnostic Interview – Revised; Lord et al., 1994, 2002) and expert judgement. Diagnoses were confirmed via the Childhood Autism Rating Scale 2 (Schopler et al., 2010), which was completed by each participant's class teacher.

Half of each population were allocated to the 'Social Feedback' condition and half were allocated to the 'Non-social Feedback' condition. Importantly, these samples of children with ASD and TD controls had very similar characteristics to the groups in Study 1 (see Table 1), enabling direct comparison. Children with ASD in the Social and Non-social Feedback conditions did not significantly differ on chronological age ($t = 0.40$, $p = .69$), BPVS age equivalent ($t = 0.04$, $p = .97$), non-verbal IQ ($t = 1.27$, $p = .21$), Leiter-3 raw score ($t = 0.85$, $p = .40$), or CARS score ($t = 0.12$, $p = .91$). TD children in the Social and Non-social Feedback conditions did not significantly differ on chronological age ($t = 0.82$, $p = .42$), BPVS age equivalent ($t = 0.04$, $p = .97$), non-verbal IQ ($t = 0.50$, $p = .62$), or Leiter-3 raw score ($t = 0.46$, $p = .65$). There were no between-population differences in BPVS age equivalent ($t = 1.08$ – 1.13 , $p = .27$ – $.29$) or Leiter-3 raw score ($t = 0.04$ – 1.21 , $p = .24$ – $.97$) across conditions, however, children with ASD were significantly older, $t(64) = 7.29$, $p < .001$, $d = 1.93$, and had significantly higher CARS scores than TD children, $t(64) = 18.84$, $p < .001$, $d = 6.16$.

3.1.2. Materials

Stimuli were exactly the same familiar and unfamiliar objects as used in Study 1. The same tray was used to present stimuli, however, an "illuminating" function was used in the Non-social Feedback condition. Underneath each section of the tray was a light bulb that could be activated by a wired switch that was concealed on the experimenter's side of the table. When switched on, the light bulb highlighted the object in the section above.

3.1.3. Procedure

The procedure was exactly as described for Study 1 with some adjustments to the referent selection trials of the word learning task (detailed below).

3.1.3.1. Social feedback condition. Eight referent selection trials (four familiar name and four novel name) followed the warm-up trials as described for Study 1. The stimuli and format were as previously described, with one exception. After children's response to each trial (whether correct or incorrect), the experimenter ostensibly named the target object with supporting social cues (see Fig. 4). They directed their gaze towards the location of the target (with accompanying head turn), pointed at the object with their index finger, and stated its name (e.g. "That is the [object name]!"). The experimenter ensured that the participant was attending to the objects before providing social cues and naming. If the child was looking elsewhere, the experimenter recaptured their attention by excitedly saying their name and/or "look!".

3.1.3.2. Non-social feedback condition. Replicating Axelsson et al.'s (2012) "highlight-target condition", the Non-social Feedback condition differed in terms of how the experimenter named the target objects. After children's responses, the experimenter discreetly flashed the light bulb underneath the target object's tray compartment on and off four times (see Fig. 4). While the light was flashing, the experimenter named the target object (e.g. "That is the [object name]!"). The experimenter looked straight at the child while the light was flashing and did not look at any of the objects in the tray (thus providing no social cues). As described above, the experimenter



Fig. 4. Examples of how feedback was provided following children's responses on referent selection trials in the Social Feedback (top) and Non-social Feedback (bottom) conditions of Study 2.

ensured that the participant was looking at the objects before activating the light and naming.

3.2. Results

3.2.1. Referent selection

Participants were scored out of four on familiar and novel referent selection trials (see Fig. 5). These data were entered into a 2(Population: TD, ASD) \times 2(Condition: Social, Non-social) \times 2(Trial Type: familiar, novel) mixed ANOVA. Main effects of Population, $F(1, 62) = 7.60$, $MSE = 0.37$, $p = .008$, $\eta_p^2 = 0.11$, and Trial Type, $F(1, 62) = 10.52$, $MSE = 0.22$, $p = .002$, $\eta_p^2 = 0.15$, were qualified by a significant Population \times Trial Type interaction, $F(1, 62) = 8.19$, $MSE = 0.22$, $p = .006$, $\eta_p^2 = 0.12$, which was explored via a series of Bonferroni-adjusted pairwise comparisons. The accuracy of TD children and children with ASD did not differ on familiar trials ($p = .34$), but TD children were significantly more accurate than children with ASD on novel trials, $t(64) = 2.97$, $p = .004$, $d = 0.91$. TD children's accuracy did not significantly differ between familiar and novel trials ($p = .33$), whereas children with ASD responded significantly more accurately on familiar trials than novel trials, $t(33) = 3.25$, $p = .003$, $d = 0.71$. No other effects or interactions were significant.

3.2.2. Retention and generalisation trials

Participants were scored out of eight on retention and generalisation trials (each novel word was tested twice on each trial type; see Fig. 6). Children were considered to have responded correctly if they selected the object that the experimenter labelled with the requested word during the referent selection stage. To explore the effects of social and non-social feedback on retention and generalisation across populations, the data were entered into a 2(Population: TD,

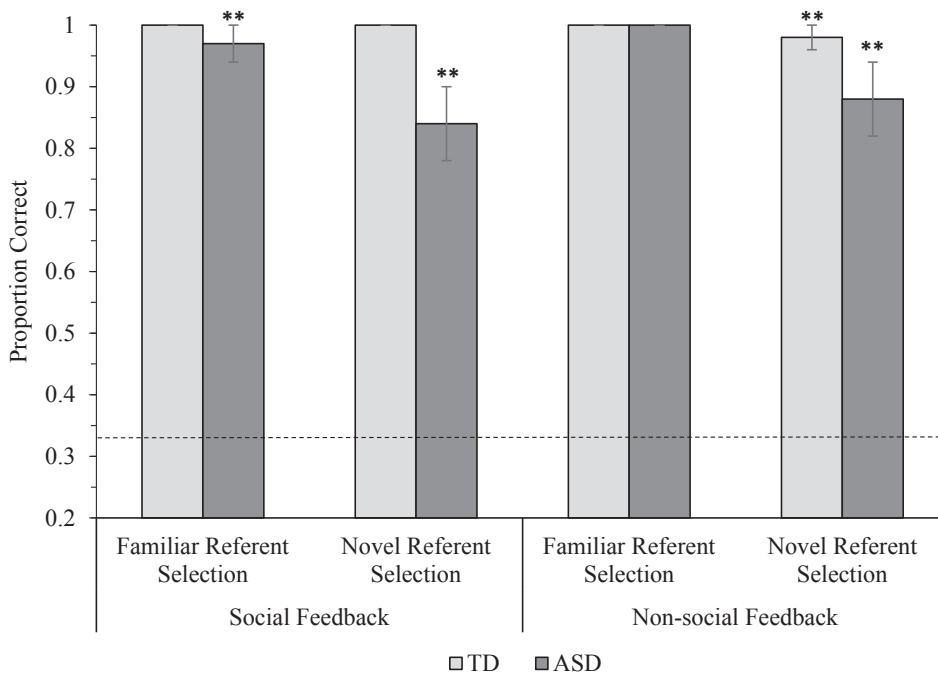


Fig. 5. Average referent selection trial accuracy for typically developing (TD) children and children with autism spectrum disorder (ASD) in Study 2. Error bars show ± 1 SE. Stars above columns indicate where below-ceiling performance was significantly more accurate than expected by chance, indicated by the dotted line (* $p < .05$; ** $p < .01$).

ASD) \times 2(Condition: Social Feedback, Non-social Feedback) \times 2(Trial Type: retention, generalisation) mixed ANCOVA. As in Study 1, novel referent selection accuracy was included as a covariate to control for initial between-group differences in word-referent mapping on children's retention and generalisation accuracy. The analysis yielded a significant main effect of Population, $F(1, 61) = 5.57$, $MSE = 4.72$, $p = .021$, $\eta_p^2 = 0.08$, which was qualified by a Population \times Condition interaction that approached significance, $F(1, 61) = 3.34$, $MSE = 4.72$, $p = .073$, $\eta_p^2 = 0.05$. Due to our a priori expectations concerning the relationship between diagnostic group and experimental condition, we examined this interaction via a series of Bonferroni-adjusted pairwise comparisons (controlling for referent selection accuracy). However, the following pairwise contrasts should be interpreted with a caution as the interaction was not significant. In the Social Feedback condition,

children with ASD responded significantly more accurately than TD children ($p = .001$, $\eta_p^2 = 0.31$). However, the two groups' delayed test accuracy did not significantly differ in the Non-social Feedback condition ($p = .96$). While children with ASD achieved significantly greater delayed test accuracy in the Social Feedback Condition than the Non-social Feedback condition ($p = .018$, $\eta_p^2 = 0.17$), the accuracy of TD children did not significantly differ between conditions ($p = .75$). The results were qualitatively similar when an ANOVA was conducted without novel referent selection accuracy as a covariate.

Given the similarity of TD children's accuracy across the two conditions, we collapsed the Social and Non-social Feedback conditions and ran one-sample t -tests with increased statistical power. As a single group, TD children who received attentional feedback retained, $t(31) = 2.57$, $p = .015$, $d = 0.45$, and generalised, $t(31) = 2.92$,

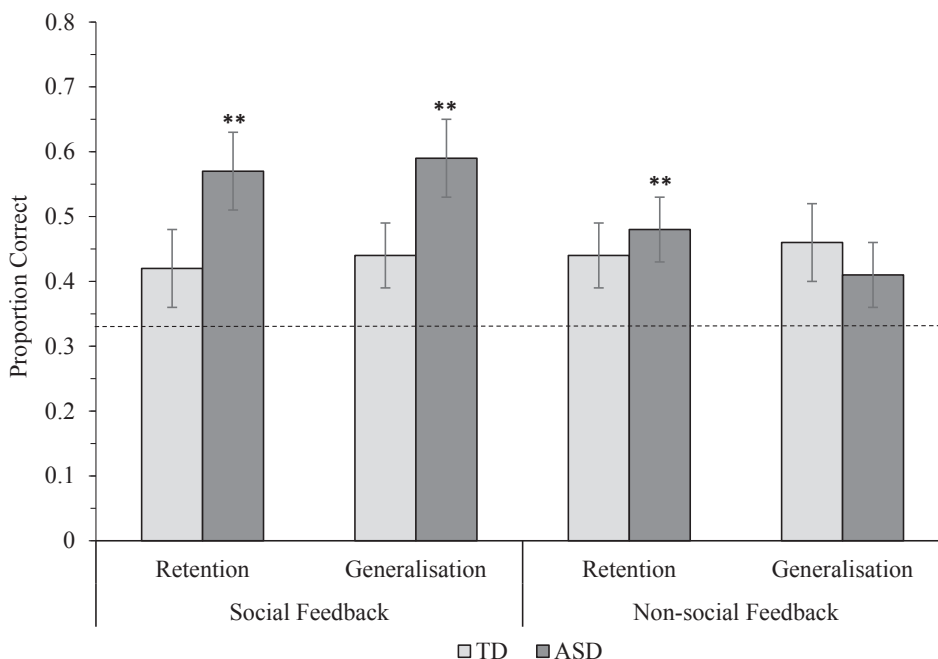


Fig. 6. Average retention and generalisation trial accuracy for typically developing (TD) children and children with autism spectrum disorder (ASD) in Study 2. Error bars show ± 1 SE. Stars above columns indicate where below-ceiling performance was significantly more accurate than expected by chance, indicated by the dotted line (* $p < .05$; ** $p < .01$).

$p = .006$, $d = 0.51$, novel labels with significantly greater accuracy than expected by chance.

In light of the surprisingly strong performance of children with ASD in the Social Feedback condition, we conducted exploratory analyses examining whether social feedback yielded significant benefits to learning in comparison to receiving no feedback (comparing across the two studies). Finding a difference of this nature would suggest that social cues can facilitate word learning in children with ASD, when provided at a particular moment during referent selection. As shown in Table 1, the ASD and TD samples that received social feedback in this study did not differ from those who received no feedback in Study 1 on receptive vocabulary or nonverbal intelligence. The ASD samples did not differ from one another on chronological age or CARS score, nor did the TD samples.

A 2(Population: ASD, TD) \times 2(Condition: Social Feedback, No Feedback (Study 1)) \times 2(Trial Type: retention, generalisation) ANCOVA, controlling for children's accuracy on novel referent selection trials, revealed a borderline Population \times Condition \times Trial Type interaction, $F(1, 60) = 1.28$, $MSE = 3.59$, $p = .06$, $\eta_p^2 = 0.06$. To establish the nature of this interaction, we deconstructed the relationship between Condition and Trial Type for children with ASD and TD children separately, though note that the interaction was marginally significant, and so the comparisons should be interpreted with caution. Children with ASD achieved significantly greater retention accuracy in the Social Feedback condition than the No Feedback condition ($p = .018$, $\eta_p^2 = 0.17$). Their generalisation accuracy did not differ significantly between conditions ($p = .11$). For TD children, between-condition differences in accuracy were not significant for retention ($p = .83$) or generalisation trials ($p = .19$). Thus, social feedback had a facilitative effect on novel word retention in children with ASD, but did not enhance the learning of TD children. Additional analyses confirmed that these results were not significantly influenced by participant gender (see footnote 1).

To explore the interdependence of fast and slow word learning processes across groups, we conducted a series of hierarchical regressions on the complete data set (Study 1 and Study 2 collapsed). Measures of word learning other than the dependent variable for each analysis (novel referent selection, retention, and generalisation accuracy) were entered in block 1, followed by receptive vocabulary (BPVS age equivalent) and nonverbal intelligence (Leiter-3 raw score) in block 2. Chronological age and autism severity scores were omitted as the TD and ASD samples differed significantly on these metrics. This approach enabled us to determine relationships between word learning abilities and identify whether developmental differences across participants have additional influences. Final models would re-apportion variance to participant characteristics (receptive vocabulary and nonverbal intelligence) in block 2 if they increased the overall amount of predicted variance. The final regression results are shown in Table 2, reporting only the significant predictors.

Novel referent selection accuracy was best predicted by a model containing retention and generalisation accuracy, plus participant characteristics, $F(4, 93) = 7.29$, $MSE = 0.40$, $p < .001$, adjusted

$R^2 = 0.21$. Receptive vocabulary was the only significant predictor ($\beta = 0.48$, $p < .001$).

Retention accuracy was best predicted by a model containing novel referent selection and generalisation accuracy, $F(2, 95) = 19.91$, $MSE = 2.22$, $p < .001$, adjusted $R^2 = 0.28$. Generalisation accuracy was the only significant predictor ($\beta = 0.53$, $p < .001$). The addition of participant characteristics did not have a significant influence on the amount of variance explained by the model.

Generalisation accuracy was best predicted by a model containing novel referent selection and retention accuracy, plus participant characteristics, $F(4, 93) = 12.51$, $MSE = 2.22$, $p < .001$, adjusted $R^2 = 0.32$. Retention accuracy ($\beta = 0.49$, $p < .001$) and nonverbal intelligence ($\beta = 0.28$, $p = .011$) were both significant predictors.

Finally, we examined whether variability in these experimental measures of word learning statistically predicted variability in children's receptive vocabulary (a reflection of "real world" word learning). BPVS age equivalent score was the dependent variable in a multiple regression model that included novel referent selection, retention, and generalisation accuracy as predictors. The model was statistically significant, $F(3, 94) = 11.53$, $MSE = 308.03$, $p < .001$, adjusted $R^2 = 0.25$. Novel referent selection accuracy was the only significant predictor ($\beta = 0.46$, $p < .001$).

3.3. Discussion

Children with ASD were less accurate in their use of ME to fast-map novel word-referent relationships than TD children (although their performance significantly exceeded chance). Contrary to our predictions, children with ASD in the Social Feedback condition responded more accurately on delayed test trials than TD controls, and children with ASD who received Non-social Feedback or no feedback (in Study 1). By contrast, TD children did not benefit significantly from either form of feedback.

Children with ASD responded less accurately than TD children on novel referent selection trials in both feedback conditions. Referent selection requires children to evaluate familiar competitors, rule them out as targets, and then shift their attention to the novel object (Halberda, 2006). While TD children are curious to engage with their environment and can flexibly shift their attention between features (Landry & Bryson, 2004), recent studies have shown that highly-salient familiar objects may interfere with referent selection by drawing their attention away from novel objects (e.g. Pomper & Saffran, 2018). It is possible that ASD, a condition characterised by abnormal fixations on specific stimuli coupled with difficulties disengaging and shifting focus (American Psychiatric Association, 2013), disrupts attentional mechanisms that enable maximally-efficient use of ME in word learning. Although pairs of familiar items in our referent selection trials were likely to be equally well-known to participants and were similarly sized, it may be that individual children with ASD were influenced by idiosyncratic preferences. That is, in some trials, participants with ASD may have been attracted to certain familiar objects and selected them impulsively without fully evaluating the complete array.

Table 2

Results of regression analyses predicting measures of word learning accuracy (novel referent selection, retention, and generalisation) and receptive vocabulary across typically developing children and children with autism spectrum disorder ($N = 98$).

Predicted variable	Final model R^2	Variable	B	SE B	β
Referent selection (novel)	0.24	Receptive vocabulary	0.02	0.004	0.48**
Retention	0.30	Generalisation	0.52	0.09	0.53**
Generalisation	0.35	Retention	0.50	0.09	0.49**
		Nonverbal intelligence	0.03	0.01	0.28*
Receptive vocabulary	0.25	Referent selection (Novel)	12.91	2.54	0.46**

Note: SE = standard error.

* $p < .05$.

** $p < .01$.

Despite their reduced referent selection accuracy and well-documented impairments in social communication (American Psychiatric Association, 2013), children with ASD responded most accurately on retention and generalisation trials in the Social Feedback condition. These results demonstrate that ostensive social feedback can enhance delayed retention and generalisation of word meanings in children with ASD, confirming the utility of a common feature of behavioural interventions such as the Picture Exchange Communication System and Applied Behaviour Analysis (Bondy & Frost, 2002). From a practical viewpoint, these findings provide insight into how interventions can specifically manipulate children's learning environment to enhance their intake of lexical information. Providing highly-salient social cues that direct children's attention to the intended referent of a novel word *after* they have actively and independently disambiguated referential meaning may strengthen encoding of the word-referent relationship, increasing the likelihood of delayed retention and generalisation.

Another key result of this study was that non-social feedback did not significantly benefit word learning in either TD children or children with ASD. One possibility is that the flashing light did not serve as an effective cue to the speaker's referential intent, however, Axelsson et al. (2012) have shown that attentional cues do not necessarily need to communicate referential intent in order to promote retention. Another possibility is that the flashing light manipulated attention in a manner that was not conducive to word learning for either group. For example, both TD children and children with ASD may have been distracted by the flashing light, diverting their attention from the target object rather than increasing fixation on it. For children with ASD in particular, the light may have been less effective at capturing and directing children's attention than the experimenter's behavior (exposure to special-education interventions that explicitly teach children to follow gaze and gestures may have primed participants with ASD in the Social Feedback condition; see Reichow & Volkmar, 2010).

It is noteworthy that, unlike the TD 2-year-olds in Axelsson et al. (2012), our samples of older TD children who received ostensive feedback did not significantly outperform those who received no feedback in Study 1. These data highlight the fact that children's visual attention may be necessary, but not sufficient, for word learning (Pomper & Saffran, 2018; Smith & Yu, 2013). Indeed, it is not uncommon to observe relatively low retention in fast mapping studies (e.g., Horst & Samuelson, 2008), and we acknowledge that our integration of multiple retention and generalisation trials per word, within the same testing stage, may have increased the cognitive demand placed on children in comparison to test phases in prior studies with younger TD children.

Interestingly, we identified relationships between children's receptive vocabulary and novel referent selection accuracy across both populations. However, referent selection did not predict retention nor generalisation of fast-mapped words. These findings suggest that increased accuracy of initial word-referent mappings does not significantly enhance the likelihood of recalling or generalising those new words after 5 min, but it may have an impact on children's long-term vocabulary development. This pattern of results aligns with the dynamic associative account's proposal that vocabulary development is driven by children's experiences with words across multiple encounters, rather than individual fast mapping instances (McMurray et al., 2012). More accurate use of ME to successfully disambiguate word meanings over multiple naming events may result in a higher frequency of correct word-referent pairings, and this increased statistical input may in turn facilitate long-term vocabulary development. Conversely, the more words that a child knows, the easier it would be for them to apply ME across diverse word learning environments. An important practical implication of this result is that scaffolding initial word-referent mappings for children with ASD may have long-term benefits for their acquisition of vocabulary.

Our data also revealed strong relationships between delayed retention and generalisation accuracy across populations. This indicates

that successfully-retrieved word-object representations encoded during referent selection privileged similarity of shape as the key determinant of referential meaning and were not restricted to precise combinations of perceptual cues. Nonverbal intelligence also contributed significantly to the prediction of generalisation accuracy, implying that children with lower intellectual functioning were less consistent in their use of shape as the basis for extending word-referent representations. Based on these findings, one might speculate that the diminished use of a shape bias in other ASD samples may be the consequence of general learning disabilities (e.g. Hartley & Allen, 2014).

4. General discussion

This study systematically explored the relationship between fast mapping, retention, and generalisation in children with ASD, and sought to identify ways of promoting their learning. Our findings reveal that, in comparison to TD controls matched on receptive vocabulary and nonverbal intelligence, children with ASD are less accurate in their use of ME to map novel word-referent relationships but are unimpaired on measures of delayed retention and generalisation. Children with ASD who received social feedback after independently mapping word-referent relationships achieved the most accurate word learning, outperforming TD controls in the same condition and autistic peers who received non-social feedback or no feedback. Together, these results provide new insight into how vocabulary acquisition is impacted by ASD and highlight potential strategies for enhancing word learning that could be utilised by interventions.

The broad similarity of the two populations' response profiles across referent selection, retention, and generalisation trials provides strong support for the dynamic associative model as an explanation for word learning in both typical development and autism (McMurray et al., 2012). The responses of TD children and children with ASD both indicate a clear distinction between rapidly identifying meaning in the moment a word is heard and successfully retaining meaning over time. These results have important implications for the extant literature focusing on word learning in ASD. As the vast majority of studies have not directly assessed retention, there is an implicit tendency to draw inferences about this process from evidence of referent selection (or lack thereof) only. The disparity between referent selection and retention identified by the present research suggests that such a theoretical approach may not be valid, as noted by Horst and Samuelson (2008), and we suggest that a fuller picture of word learning requires direct assessment of integrated processes that occur over short and long time-scales. Our findings also demonstrate that ASD does not impair the fundamental mechanisms that underpin word learning. When expectations are based on current receptive language ability rather than chronological age, children with ASD can learn novel words as effectively as TD children under the right conditions. Thus, our data add to a growing body of evidence indicating that language acquisition in ASD may be delayed or slowed, but not qualitatively deviant (e.g. Boucher, 2012; Charman, Drew, Baird, & Baird, 2003; Ellis Weismer et al., 2011; Gernsbacher, Morson, & Grace, 2015; Gernsbacher & Pripas-Kapit, 2012; Goodwin, Fein, & Naigles, 2012; Naigles, Kelty, Jaffery, & Fein, 2011; Waterhouse & Fein, 1982).

Rather than affecting the processes that support word learning, ASD may affect language acquisition by disrupting children's intake of information (Arunachalam & Luyster, 2016; Tenenbaum, Amso, Righi, & Sheinkopf, 2017). Impairments in social-cognition and communication may reduce the likelihood that children with ASD will utilise gaze and gestural cues when deciphering the meanings of words (e.g. Baron-Cohen et al., 1997), slowing and reducing the accuracy of mapping new word-referent relationships. Children with ASD may also be increasingly distracted by irrelevant features of the learning environment, or be adversely affected by how information is presented. For example, Tenenbaum et al. (2017) recently found that holding a target object near a speaker's mouth facilitated learning in children with ASD,

whereas holding the object far from their mouth hindered performance (children's attention was divided between the two features of the visual scene, reducing the strength of the encoded word-referent association). In the present study, difficulties that affect the intake of novel lexical input appeared to be mitigated by presenting visual and auditory stimuli in a way that appealed to the strengths of children with ASD. Firstly, children actively and independently disambiguated referential meaning based on an unimpaired lexical heuristic, and were not required to interpret ostensive labelling or other forms of external information. Secondly, social feedback was provided *after* children had mapped word-referent relationships, re-focusing their attention on the target and strengthening its association with the novel word. Having already figured out what the novel words represented, children did not need to infer communicative intent from the experimenter's cues – they just had to re-direct their attention in order to benefit from the repeated exposure to the word-referent pairing.

Crucially, studies such as this are vital for understanding the optimal language-learning conditions for children with ASD. Presenting new words under such conditions will most likely increase the probability of intake and ultimately promote long-term vocabulary development, as suggested by our regression analyses linking referent selection accuracy and size of receptive vocabulary (Arunachalam & Luyster, 2016). The systematic presentation of new words alongside familiar words, coupled with post-mapping attentional feedback, are strategies that could potentially be employed by interventions to scaffold children's vocabulary acquisition in clinical and educational contexts.

Most unexpectedly, children with ASD responded with greater accuracy on retention and/or generalisation trials than vocabulary-matched TD children in two out of three between-subjects conditions across both studies. It may be that once children's understanding of language is sufficiently advanced, enhanced perceptual functioning in ASD (Motttron et al., 2006) benefits children's encoding of word-referent relationships established through fast mapping. Superior attention to visual features may elicit more robust encoding of word-object associations when exposures are brief, and be increasingly beneficial when effective attention-directing feedback provides additional opportunities to examine referent objects. Heightened auditory sensitivity in ASD may also facilitate word learning. Norbury et al. (2010) proposed that enhanced phonological learning may provide a compensatory mechanism that supports mapping of word-object associations despite impairments in social understanding. However, these explanations are speculative, and further research is required to understand how differences in visual and auditory processing influence fast mapping and delayed word learning in ASD.

It is conceivable that the learning of our TD participants would have been promoted if the novel word-referent relationships were mapped via ostensive labelling rather than ME-driven referent selection. The benefits of ostensive labelling and associated social-pragmatic cues (e.g. gaze, pointing, joint attention, affect) to lexical acquisition in typical development are extremely well-documented (e.g. Baldwin, 1993; Nappa, Wessel, McEldeen, Gleitman, & Trueswell, 2009; Poulin-Dubois & Forbes, 2002). Those studies that assess long-term learning have shown that children aged 2- and 3-years can retain novel words for up to one month if referents are ostensively labelled (Carey & Bartlett, 1978; Goodman, McDonough, & Brown, 1998; Markson & Bloom, 1997; Vlach & Sandhofer, 2012). Thus, for TD children, word-referent relationships encoded through ostensive labelling may be more robust than those encoded through ME referent selection. However, providing cues during mapping that eliminate the problem of referential ambiguity (e.g. explicitly telling children the name of a target object) prevents children from forming independent inferences about the links between words and objects (Axelsson et al., 2012). This kind of passive learning, which hinges on children's ability to interpret external input in social contexts, may be particularly vulnerable to cognitive and communicative impairments in ASD. Consequently, children with ASD

may be more likely to retain word-referent relationships that they actively encode through ME referent selection.

When interpreting the results of our ASD samples, it is important to consider that they were matched to TD controls on receptive vocabulary, not chronological age (the ASD samples were significantly older than their TD counterparts). Previous studies comparing myriad aspects of language development in ASD against chronological age norms for TD children have consistently found impairments (e.g. Charman et al., 2003). Consequently, we acknowledge the likelihood that children with ASD in the present study may have achieved significantly lower accuracy than similarly-aged TD controls. However, the purpose of this study was to compare word learning abilities across autism and typical development when delays in language development were controlled for.

Of course, we must address the study's limitations. Firstly, the strong performance of children with ASD may, at least in part, be attributed to the tightly controlled setting. Participants were presented with arrays of just three objects, mapping was not contingent on attention to exogenous factors, distractions were minimized, and feedback was strategically timed and highly-salient. However, natural language-learning environments are noisy, rife with distractions, and there may be numerous familiar and novel objects present during a naming event. Thus, it is possible that very different results would be obtained under "real world" learning conditions (Yurovsky, Smith, & Yu, 2013). Also, as we only tested children's ability to learn word-object relationships, we cannot rule out the possibility that our samples differed on other aspects of language use (e.g. pragmatic understanding, production, ability to learn non-noun word categories, etc). Secondly, it is important to acknowledge that language development in ASD is extremely heterogeneous. While ME-based referent selection may be a strength for most of the population, retention and appropriate generalization of word-referent relationships are likely to be highly varied (particularly when learning conditions are less favorable). As differences in these abilities can be observed in ASD samples with less-developed receptive vocabularies (e.g. Hartley & Allen, 2014), it may be that word learning difficulties diminish as children's lexical development unfolds. Thirdly, it should be noted that some statistically significant effects were components of marginally significant interactions. As such, the results from these analyses should be regarded with a degree of caution. Finally, in addition to attentional feedback, there are many other factors that influence the likelihood of successfully learning fast-mapped words. Studies with TD children have demonstrated that retention is mediated by objects' spatial locations (Axelsson, Perry, Scott, & Horst, 2016), the number of competitors (Horst et al., 2010), variability in the learning environment (Twomey, Ma, & Westermann, 2018), and contextual repetition (Axelsson & Horst, 2014). Exploring how such factors influence word learning in children with ASD is an important objective for future research and necessary to refine understanding of the optimal language-learning conditions for this population.

Conflict of interest

Hartley declares that he has no conflict of interest. Bird declares that she has no conflict of interest. Monaghan declares that he has no conflict of interest.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cognition.2019.03.001>.

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